STATE OF NEW YORK
CONSERVATION DEPARTMENT
WATER RESOURCES COMMISSION

TIME-OF- TRAVEL STUDIES IN THE FALL CREEK BASIN TOMPKINS COUNTY, NEW YORK

INCLUDING LOW-FLOW CHARACTISTICS

By

BERNARD DUNN
U. S. GEOLOGICAL SURVEY

REPORT OF INVESTIGATION
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UNITED STATES DEPARTMENT OF THE INTERIOR
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ABSTRACT

The time of travel of stream water was determined for a 19.9-mile reach of Fall Creek from McLean to the U.S. Geological Survey gaging station near Ithaca, Tompkins County, and for a 5.2-mile reach of Virgil Creek from Dryden to its mouth. The time of travel for Fall Creek during a very low discharge of 9 cfs (cubic feet per second) was more than four times as great as when a medium discharge of 100 cfs prevailed. Channel irregularities and manmade obstructions cause the time of travel through a reach to vary erratically during low flows. For moderate discharges the time of travel was much more uniform throughout the reaches studied. Flow-duration curves were developed and are presented for three sites: (1) the gaging stations on Fall Creek near Ithaca; (2) on Fall Creek at McLean; and (3) on Virgil Creek at Freeville.

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INTRODUCTION

In April 1963 the New York State Department of Health, at the request of the Tompkins County Health Department, requested the Geological Survey to assist in the determination of the waste assimilative capacity of Fall Creek and Virgil Creek in Tompkins County. The specific request was to make time-of-travel studies, to obtain discharge measurements at critical sites, to analyze streamflow data by providing duration studies on both streams, and to determine the annual minimum 7-day mean flow for a 10-year return period. The survey was made during the period June 4 to October 18, 1963.

The original report was prepared for open-file release in 1964, as part of the cooperative agreement between the New York State Department of Health and the U.S. Geological Survey. The field work was supervised by Donald F. Dougherty, former district engineer of the Water Resources Division, U.S. Geological Survey, and the preparation of this report was supervised by Garald G. Parker, former district chief.

Time-of-travel studies, made by introducing a fluorescent dye tracer into the water at the beginning of a reach and analyzing samples taken at the end of the reach, proved very effective in measuring stream velocity in Fall Creek basin. The time of travel is dependent on many factors such as length of the reach, discharge and velocity of the stream, and natural and manmade effects. During times of low flows, meandering in the stream, and the effects of natural and manmade barriers, such as dams, logs, and debris, decreased the velocity of the water.

DESCRIPTION OF BASIN

Fall Creek rises in Cayuga County just east of the village of Sempronius and flows in a southerly direction to a point below McLean, where it turns in a southwesterly direction and flows through the communities of Freeville, Varna, and Ithaca into Cayuga Lake. Virgil Creek, principal tributary to Fall Creek, rises in an area north of Virgil and joins Fall Creek from the southeast just below Freeville. Fall Creek, at the gaging station upstream from Beebe Lake (2 miles upstream from the mouth) drains an area of 126 square miles, of which 40.9 square miles is drained by Virgil Creek. A map of the Fall Creek basin is presented in figure 1.

Fall Creek and Virgil Creek lie within the southern New York section of the Appalachian Plateau province of New York. The bedrock topography is a mature plateau region of a cuesta form, with features of topographic youth superimposed on it by continental glaciation.

Two fundamental topographic types are present in the basins: (1) the preglacial features, of which the east-west trending Portage escarpment dominates the uplands; and (2) the glacially modified terranes characteristic of the lowlands.

A combination of glacial features are found in the Fall Creek valley along the base of the Portage escarpment at the lower reach of the stream. This is a subsequent valley of preglacial origin and retains in general its original configuration, but in detail it has been modified by a masking of glacial deposits and by the development within its confines of the post-glacial valleys.

The variations in topography are reflected in the time of travel of the waters in Fall Creek basin, as will be shown later in the report.

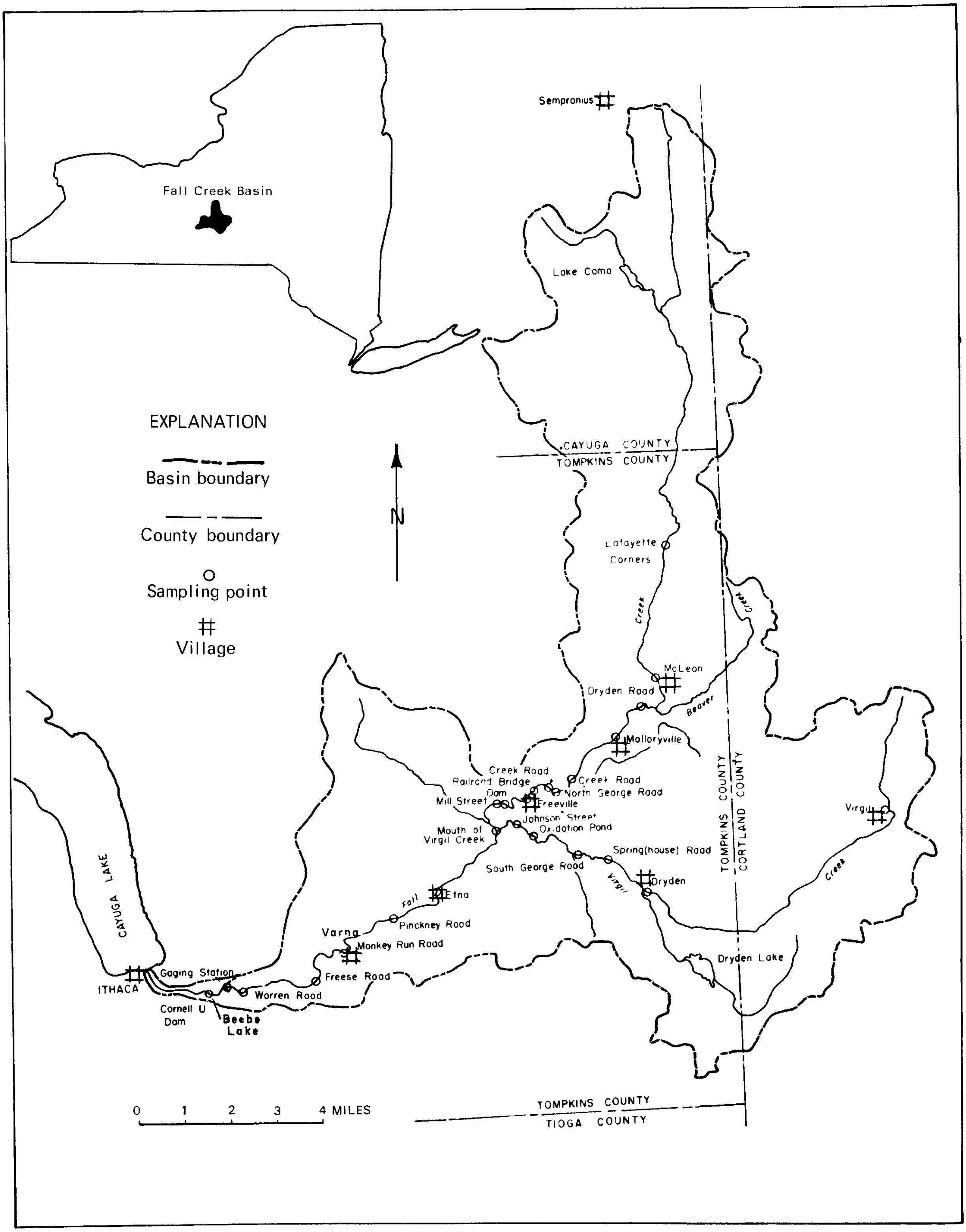

Figure 1.--Location of sampling points in Fall Creek basin, N.Y.

STREAMFLOW

In the Fall Creek basin, continuous streamflow data are available for Fall Creek near Ithaca since 1925. The gaging station (drainage area, 126 sq mi) is on the left bank in Forest Home, half a mile upstream from Cornell University dam, 1 1/2 miles northeast of Ithaca, and 2 miles upstream from the mouth at Cayuga Lake.

A series of discharge measurements on Fall Creek at McLean (drainage area, 40.2 sq mi) were made during the time-of-travel studies. A duration curve of flow was developed by comparing these measurements with the flow at the Ithaca (Forest Home) gage. The measuring sites are shown in figure 1.

Periodic discharge measurements have been made on Virgil Creek at the Johnson Street bridge, Freeville, (drainage area, 40.3 sq mi) since 1955. At the time of each discharge measurement, the stage of the stream was determined and from this a stage-discharge relation curve drawn (fig. 2).

During each time-of-travel study, discharge measurements were made at selected points to determine the amount of dye needed for the study. The results of these measurements are listed in table 1.

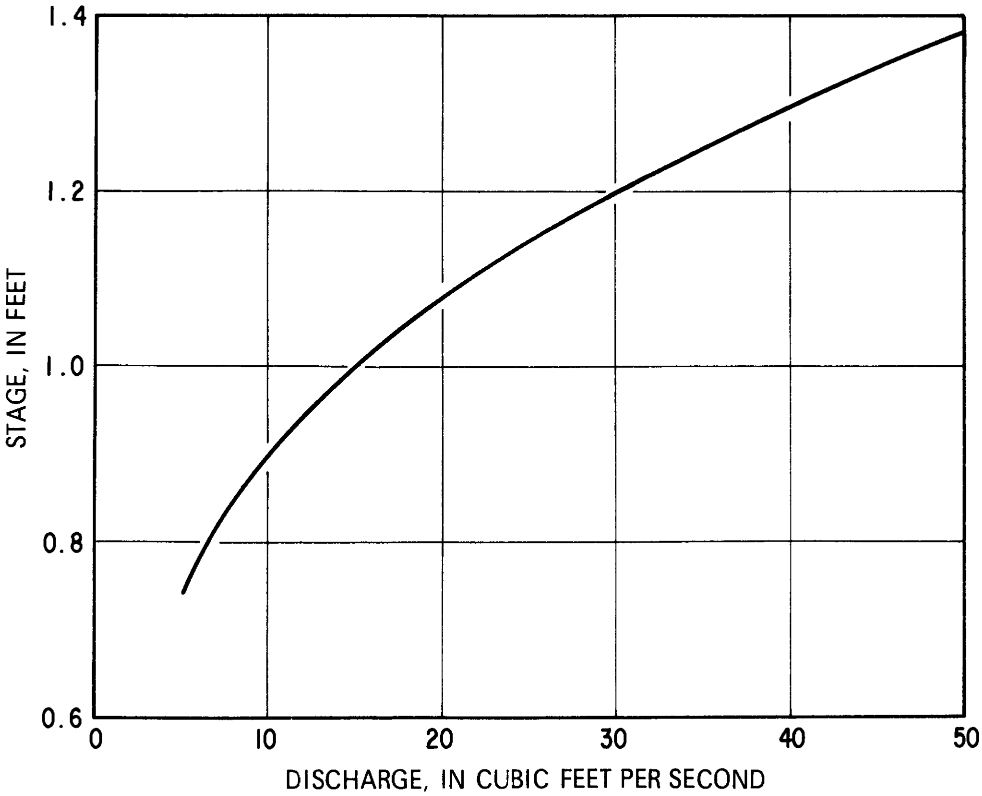

Figure 2.--Stage-discharge relationship of Virgil Creek at Johnson Street, Freeville.

Low-Flow Characteristics

To interpret properly the results of the time-of-travel studies, the low-flow characteristics of the streams involved need to be evaluated. How often can rates of flow of certain magnitudes be expected, and for how long may such flows persist?

In a study of the low-flow characteristics of a stream, a flow-duration curve is a valuable tool. It represents the frequency of occurrence of rates of streamflow without showing the chronological sequence. It indicates the percent of time, within a given period, during which selected discharges were equalled or exceeded. The curve may be used as a basis for comparison of one basin with another. For a long record, the flow-duration curve can be used as a guide to flows which may be expected in the future.

In a strict sense, the flow-duration curve applies only to the periods for which data were used to develop the curve, or to the period to which the curve is adjusted. Flow-duration curves based on short-term records are unreliable for predicting future patterns of flow. However, the reliability of a short record can be increased by adjusting it to a longer period. The method used is based on the assumption that a relationship established between the streamflow at two stations, based on a short period of concurrent records, represents also the relation between the stations for a longer period, of which records are available at one of the stations.

Discharge measurements were also made on small tributaries leading to Fall Creek from proposed housing developments and existing trailer parks. The results are listed below.

Site	Discharge (cfs)		
	June 6	August 1	October 16
Lucente Tract at Etna	0.04	0	0
Schawn Trailer Park near Etna	.12	0	0
Lucente Tract near Varna	.03	0	0
Taggin Wagon Trailer Park at Varna	e.01	0	0

e Field estimate.

Table 1.--Discharge measurements at miscellaneous sites, Fall Creek basin, 1963

Date	Site	Mean depth (ft)	Area (sq ft)	Discharge (cfs)
June 5	Fall Creek at Lafayette Corners	0.6	25.6	30.7
July 31	do.	.3	10.1	8.0
Oct. 16	do.	.2	3.7	3.0
June 5	Fall Creek at McLean	.7	24.8	36.5
July 31	do.	.3	9.2	10.3
Oct. 16	do.	.3	4.4	4.2
June 5	Fall Creek at Malloryville	1.0	48.3	48.0
Oct. 16	do.	.4	6.2	6.5
June 5	Fall Creek at Freeville	.9	44.8	52.8
June 6	Virgil Creek at State Highway 38, at Dryden	.5	9.4	12.1
Aug. 1	do.	.4	6.0	5.4
Oct. 17	do.	.4	4.3	2.6
June 6	Virgil Creek at Spring (house) Road near Dryden	.6	16.4	18.8
Aug. 1	do.	.5	11.5	8.0
Oct. 17	do.	.4	8.4	3.2
Aug. 1	Virgil Creek at Johnson Street at Freeville	.4	9.9	9.4
Oct. 17	do.	.3	7.4	5.3
June 6	Virgil Creek at mouth, near Freeville	.9	31.1	23.8
June 5	Fall Creek below Virgil Creek near Freeville	1.0	70.1	90.6
July 31	do.	.6	38.6	32.8
Oct. 15	do.	.6	27.7	13.0

Table 1.--Discharge measurements at miscellaneous sites, Fall Creek basin, 1963 (Continued)

Date	Site	Mean depth (ft)	Area (sq ft)	Discharge (cfs)
June 4	Fall Creek at Etna	1.1	75.4	82.5
July 30	do.	.8	42.9	32.8
June 4	Fall Creek at Pinckney Road near Etna	1.7	87.4	87.2
July 30	do.	.7	25.8	35.3
Oct. 15	do.	.7	17.0	13.7
June 4	Fall Creek at Monkey Run Road, at Varna	.9	47.9	103
Oct. 15	do.	.5	13.1	12.4
June 4	Fall Creek at Freese Road at Varna	.8	50.2	98.5

At times it is desirable to develop a flow-duration curve at a site where only base-flow (flow composed entirely of ground water or other delayed effluent) measurements have been made. This is done by comparing the discharge data obtained at the base-flow site with that of nearby gaging stations where long-term records are available, after it has been established that a correlation does, in fact, exist.

The shape of the flow-duration curve reflects the hydrologic, topographic and geologic characteristics of the drainage basin. The slope of the curve indicates the variability of the flow with time. A flat slope at the lower end of the curve reflects the presence of storage, which may be on the earth's surface in lakes, ponds or swamps, or in ground-water reservoirs. A steep slope at the low-flow end of the curve indicates rapidly receding baseflows due to the absence of storage.

A flow-duration curve was developed for the gaging station site on Fall Creek near Ithaca for the period 1926-59 (fig. 3). The slope of the lower part of this curve is relatively flat, which reflects a fair low-water yield.

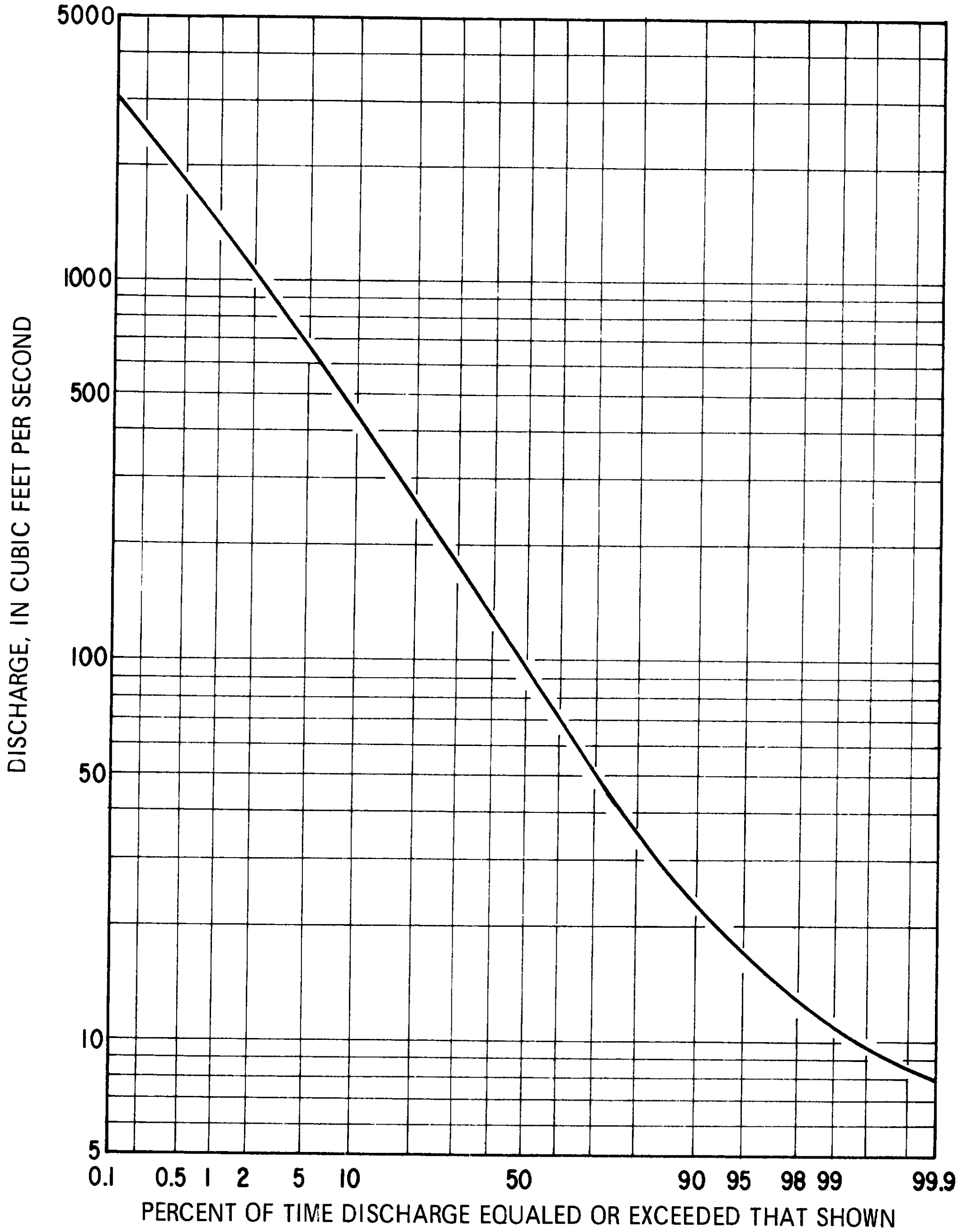

Figure 3.--Duration curve of daily flow, Fall Creek near Ithaca, 1926-59.

Flow-duration curves between 50 and 99.9 percent of time were developed for two sites of approximately equal drainage areas, where base-flow measurements were made, and are presented with that of Fall Creek near Ithaca (for the same range) in figure 4. One site is on Fall Creek at McLean (drainage area 40.2 sq mi) and the other on Virgil Creek at Johnson Street, Freeville (drainage area 40.3 sq mi).

A comparison of the curves for these sites (fig. 4) shows that, although the drainage areas are about the same, Fall Creek above McLean has

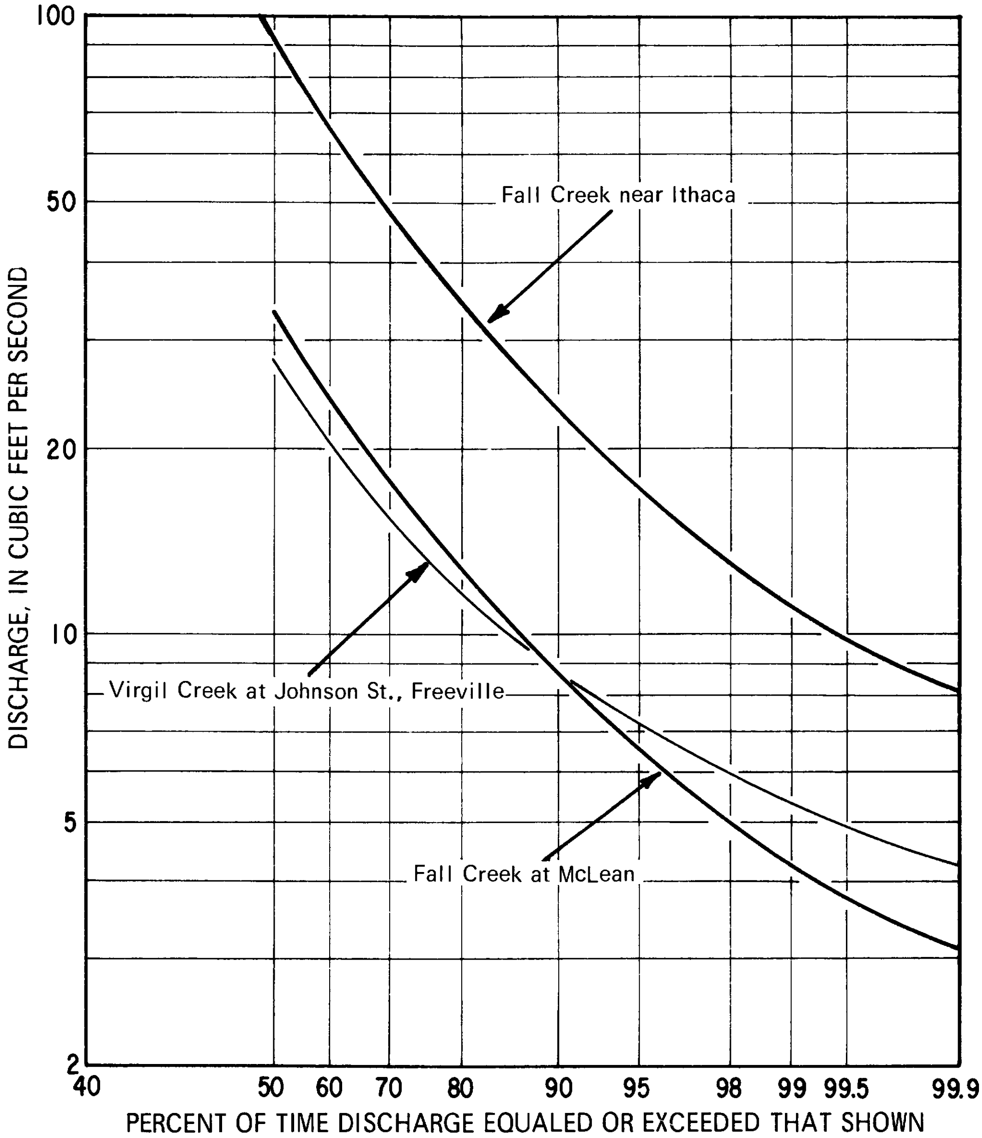

Figure 4.--Duration curves of daily flow, Fall Creek basin.

a higher yield than Virgil Creek when the flow is greater than the 90-percent value. When the flow is less than the 90-percent value, the yield of Fall Creek above McLean is less than that of Virgil Creek.

Another way to compare the flow characteristics above the sites is on a discharge-per-square-mile basis, as shown in figure 5. The curve for Fall Creek near Ithaca is unadjusted in that it does not take into consideration the water diverted by Cornell University for its water supply. If this curve were adjusted upward by 2.56 cfs (the reported average diversion for water supply by Cornell University), the Ithaca and McLean curves would practically coincide at the low ends.

The outflow from Dryden Lake, which enters in the subreach between Dryden (State Highway 38) and Spring (house) Road, modified the yield of Virgil Creek. This was especially so when the discharge on Virgil Creek was greater than the 90-percent value. The water from Dryden Lake flows over a wooden dam which has a fixed crest elevation. The outflow from

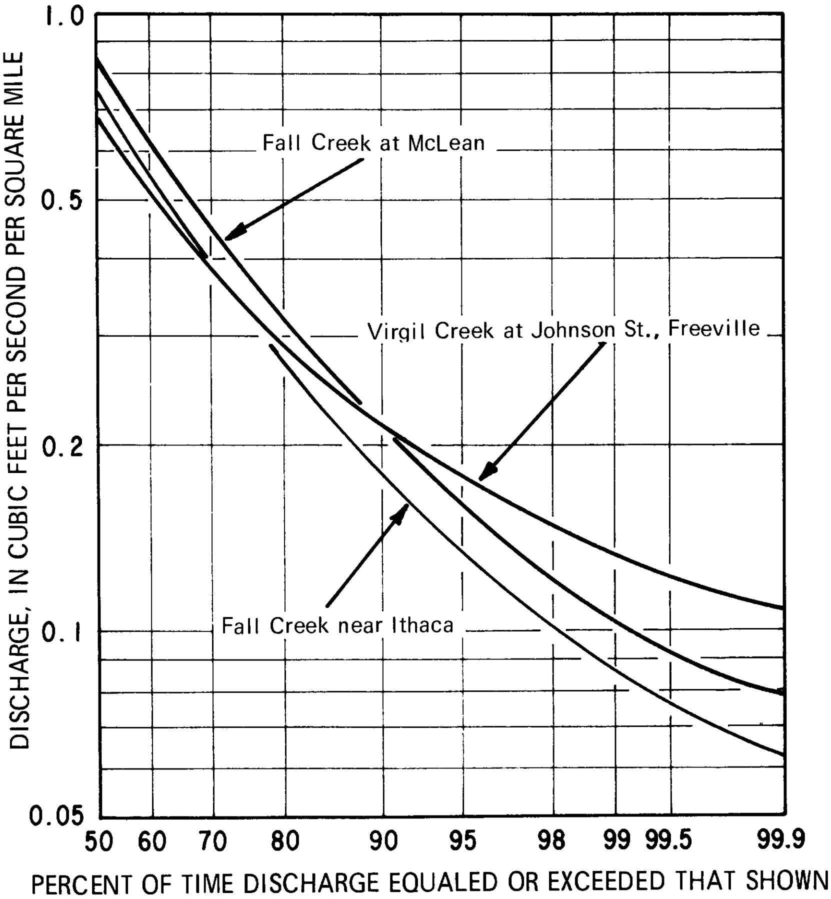

Figure 5.--Duration curves of daily flow in cubic feet per second per square mile, Fall Creek basin.

from Dryden Lake was determined by subtraction between concurrent discharge measurements made at State Highway 38 and Spring (house) Road. The inflow to Virgil Creek amounted to 19 percent when the total flow of Virgil Creek at Spring (house) Road was 3.2 cfs and 36 percent when the total flow was 18.8 cfs. The drainage basin of Dryden Lake comprises 22 percent of the total drainage area of Virgil Creek above Spring (house) Road.

Low-flow frequency curves provide another means of studying the characteristics of a stream. They are useful in that average flow for a period of consecutive days is combined with the probability of recurrence. Low-flow frequency data are presented in table 2 for those sites for which flow-duration curves were developed. The data presented are the annual minimum 7-day mean flow with a return period of 10 years.

Table 2.--Annual minimum 7-day mean flow for a 10-year return period

Site	Discharge (cfs)
Fall Creek at McLean	4 (estimated)
Virgil Creek at Johnson St., Freeville	5 (estimated)
Fall Creek near Ithaca	10

TIME-OF-TRAVEL INVESTIGATIONS

Time-of-travel studies were conducted on Fall Creek and Virgil Creek during the periods June 3-7, July 29-Aug. 3, and Oct. 14-18 at different flow-duration values and under base-flow conditions. The technique used was to introduce a fluorescent tracer, Rhodamine B, into the streams and to detect the movement of the tracer by an analytical instrument.

Rhodamine B is an excellent tracer in that it is readily detected in concentrations as low as 0.05 ppb (parts per billion). The fluorescence of Rhodamine B is not affected by the pH of the medium in the range 4.0 to 10.5. However, the fluorescence decreases with increasing temperature. This temperature coefficient is large enough that, for accurate determi-ations, the temperature of samples should be monitored.

The analytical instrument used to detect the fluorescent tracer in the waters is a Turner Model III Fluorometer. The fluorometer is basically an optical bridge that measures the difference between light emitted by the tracer sample and that for a calibrated rear-light path. The fluorometer can be used as field or laboratory instrument. As a field instrument it can be equipped with a continuous-flow cuvette so that continuous records may be obtained by pumping samples through the instrument. With a standard cuvette-holder door, in lieu of a continuous-flow cell, individual samples can be analyzed.

Both methods have been used in the field, but in most cases the individual sample technique proved to be the most efficient. This was especially true when the reaches were short and insufficient time was available to move the fluorometer from site to site. Where the sites were close together, a field laboratory was set up at a central location. The individual samples from the sites were analyzed at the field laboratory to determine the arrival of the leading edge, the peak concentration, and the trailing edge of the dye. The samples were later rerun in the office where better control of the sample and instrument temperatures could be maintained.

Procedures

Division of Streams into Study Subreaches

Time-of-travel studies were conducted on Fall Creek from McLean to the gaging station at Forest Home above Beebe Lake near Ithaca, a distance of 19.9 miles. On Virgil Creek, the study was made from Dryden, at State Highway 38 bridge, to its mouth, a distance of 5.2 miles. Three time-of-travel runs at different rates of flow were made on both Fall Creek and Virgil Creek. On Fall Creek the runs were made when the discharges at the gaging station were at about the 50, 85, and 99.6 percent flow-duration values. On Virgil Creek the runs were made when the discharges at the Johnson Street Bridge were at about the 55, 88, and 99.2 percent flow-duration values.

To study the time of travel of the water, Fall Creek was divided into nine subreaches as follows:

McLean to Malloryville
Malloryville to North George Road
North George Road to Freeville
Freeville to mouth of Virgil Creek
Mouth of Virgil Creek to Etna
Etna to Pinckney Road
Pinckney Road to Monkey Run Road
Monkey Run Road to Freese Road
Freese Road to Ithaca gaging station

On Virgil Creek the stream was divided into the following four subreaches:

Dryden at State Highway 38 to Spring (house) Road
Spring (house) Road to South George Road
South George Road to Johnson Street, Freeville
Johnson Street, Freeville to mouth

At the time of the last study, which was made in October 1965 when the flow was at the 99.6-percent duration value at the Ithaca gaging station, it was necessary to subdivide several of the subreaches on both Fall and Virgil Creeks, due to the reduced velocities and consequent increased time of travel within the subreaches.

On Fall Creek, the subreach from McLean to Malloryville was subdivided at the bridge where Dryden Road crosses Fall Creek, and subreach from Malloryville to North George Road was subdivided at Creek Road crossing. The subreach from North George Road to Freeville was subdivided by the addition of sampling points at Creek Road crossing just below North George Road and at the first railroad bridge above Freeville. The subreach from Freeville to the mouth of Virgil Creek was subdivided by the addition of a sampling point at the Freeville municipal dam, and the subreach from Freese Road to the gaging station by adding a sampling point at Warren Road. On Virgil Creek, the subreach from South George Road to Johnson Street was subdivided at a point above the outlet of the George Junior Republic Oxidation Pond.

Field Technique

Rhodamine B solution was injected into the stream at the head of each subreach by either of two methods. One method was to instantaneously inject the dye into the main thread of the stream; the other was to meter out the dye across the stream at a riffle. The method used was determined by the conditions at the injection point. The amount of dye injected into the stream was dependent on the length of the subreach quantity of water, estimated velocity in the subreach, and the desired concentration. Excellent results were obtained when the peak concentration in the subreach was between 10 and 20 ppb.

Samples of the water were taken at various time intervals at the end of the subreach and the fluorescence of the waters analyzed as previously described.

ANALYSIS OF DATA

The time of travel of the water is based on the arrival of the peak concentration of the dye at the sampling point. Turbulence and non-uniform flow in the subreach tend to spread the dye so that small concentrations usually arrive in advance of the maximum concentration. The maximum concentration is followed by dye of lesser concentration which gradually disappears.

The relation of the time of travel in each subreach of Fall Creek to the varying discharges is presented in figure 6 for the subreach from McLean to the mouth of Virgil Creek, and figure 7 for the subreach from the mouth of Virgil Creek to the gaging station near Ithaca. The mean daily discharge is that recorded at the gaging station. A relation of the time of travel for selected discharges to the length of the subreach was prepared (fig. 8). The plotted points for each selected discharge were connected by straight lines.

As can be seen from figure 8, the time of travel from McLean to the Ithaca gage, a distance of 19.9 miles, was 50 hours when the discharge was 50 cfs, and 139 hours when the discharge was 9 cfs. Time of travel of the water for intermediate discharges can be obtained from the chart by interpolation.

The effects of manmade structures are very noticeable in figure 8. In the subreach from Freeville to the mouth of Virgil Creek, where a dam is located, the velocity is decreased and the time of travel is increased. At low discharges the effects are greatest, and the backwater created by the dam extends upstream into the subreach from North George Road to Freeville. In addition, a small natural log dam below Mill Street in Freeville reduced the velocity in the subreach during periods of low discharges. In the subreach from Freese Road to the Ithaca gaging station the same relative condition exists. In this subreach, three ponds created by dams cause an increase in the time of travel within the subreach.

Natural factors, such as changes in cross-sectional area, logs across the stream, and growth of aquatic vegetation in the stream, also affect the rate of flow in a stream. These factors are always present in the stream and vary from place to place and from time to time.

On Virgil Creek the relation of the time of travel in each subreach to the discharge is shown in figure 9. The relation of time of travel for selected discharges to the length of the reach is shown in figure 10. The discharge shown is the mean daily discharge for the partial-record station. at Johnson Street, Freeville, computed from several readings of stage converted to discharge by means of figure 2.

The time of travel of water in Virgil Creek from Dryden (State Highway 38) to the mouth, a distance of 5.2 miles, was 40.2 hours when the discharge at Johnson Street in Freeville was 5 cfs; with a discharge of 25 cfs, the time of travel was 11.8 hours. The time of travel can be obtained for intermediate points from the graph by interpolation.

In figure 10, the rate of movement down a meandering stream with slow velocity and flat slope is shown in the subreach from Spring (house) Road to South George Road. In the subreach from Johnson Street to the mouth the sharp rise in the curve was a result of a reduction in the velocity of the water caused by a dam within the subreach.

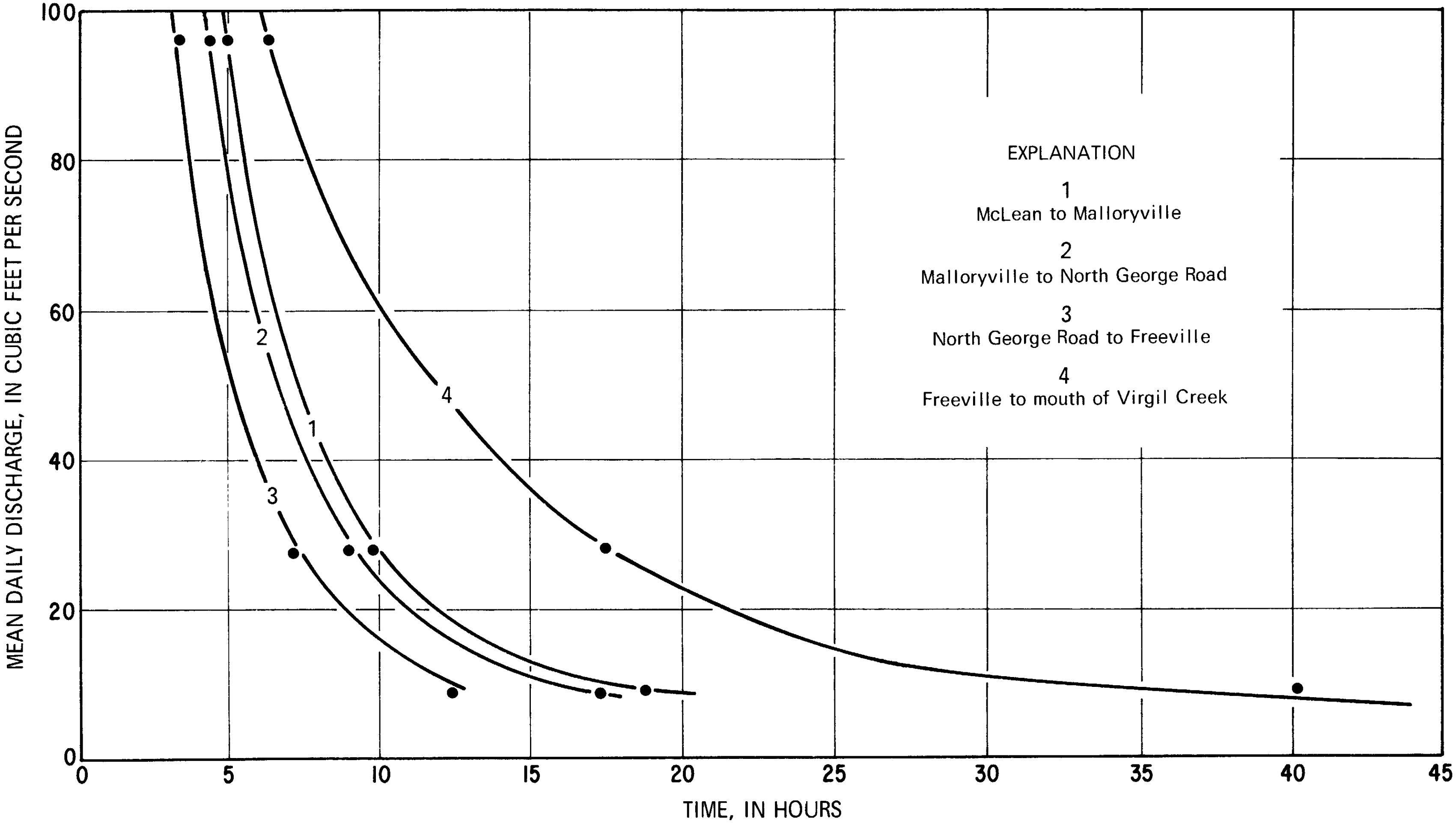

Figure 6.--Relationship of mean daily discharge and time of travel, Fall Creek, McLean to mouth of Virgil Creek.

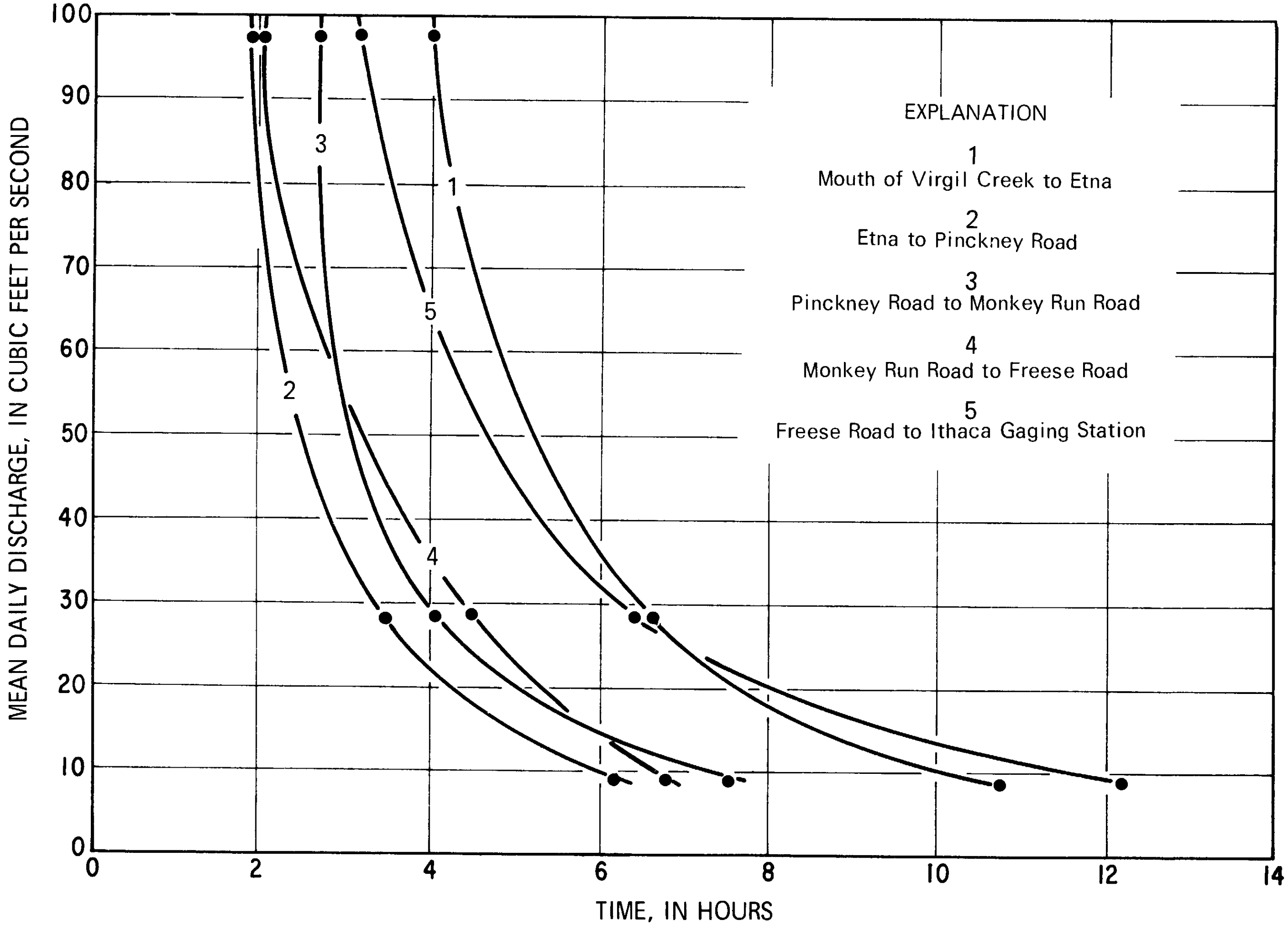

Figure 7.--Relationship of mean daily discharge and time of travel, Fall Creek, mouth of Virgil Creek to Ithaca gaging station.

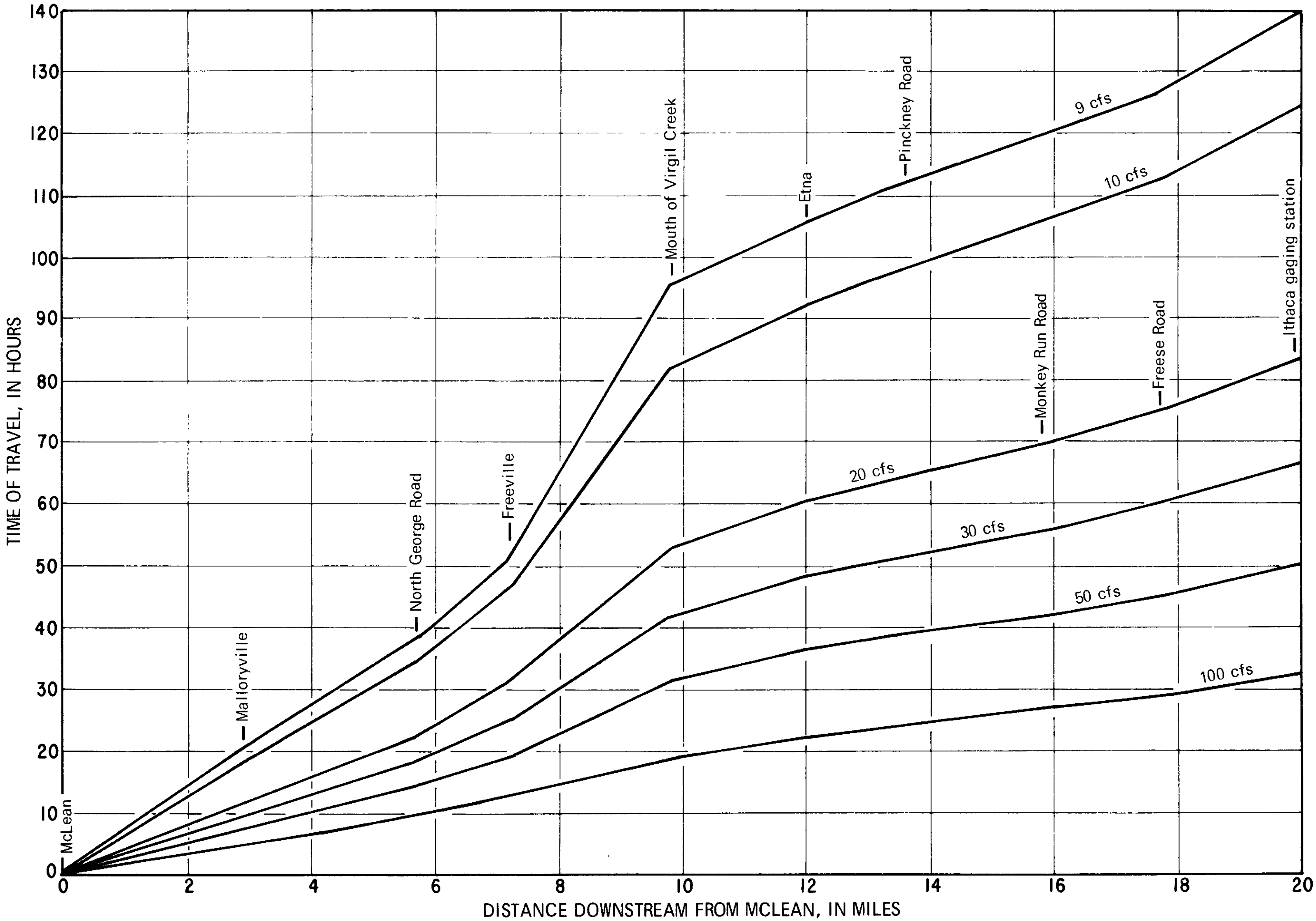

Figure 8.--Time of travel, Fall Creek, McLean to Ithaca gaging station.

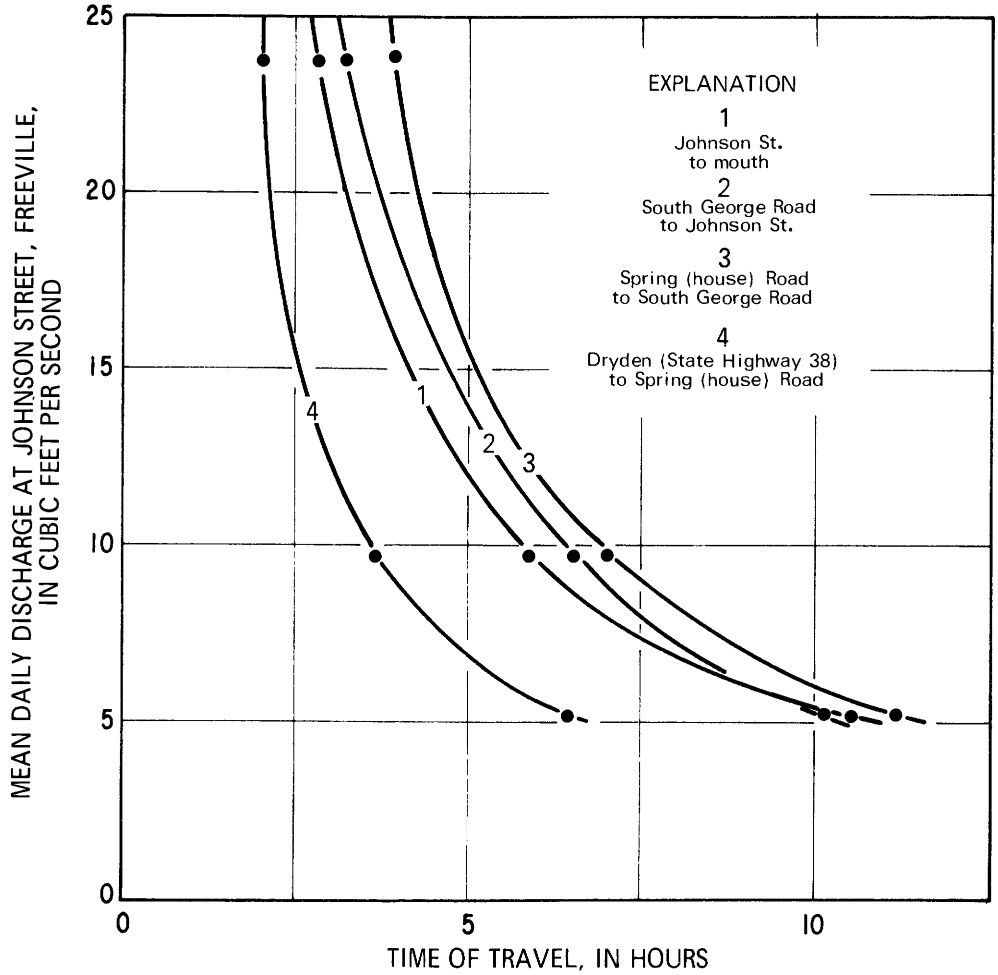

Figure 9.--Relationship of mean daily discharge and time of travel, Virgil Creek, Dryden (State Highway 38) to mouth.

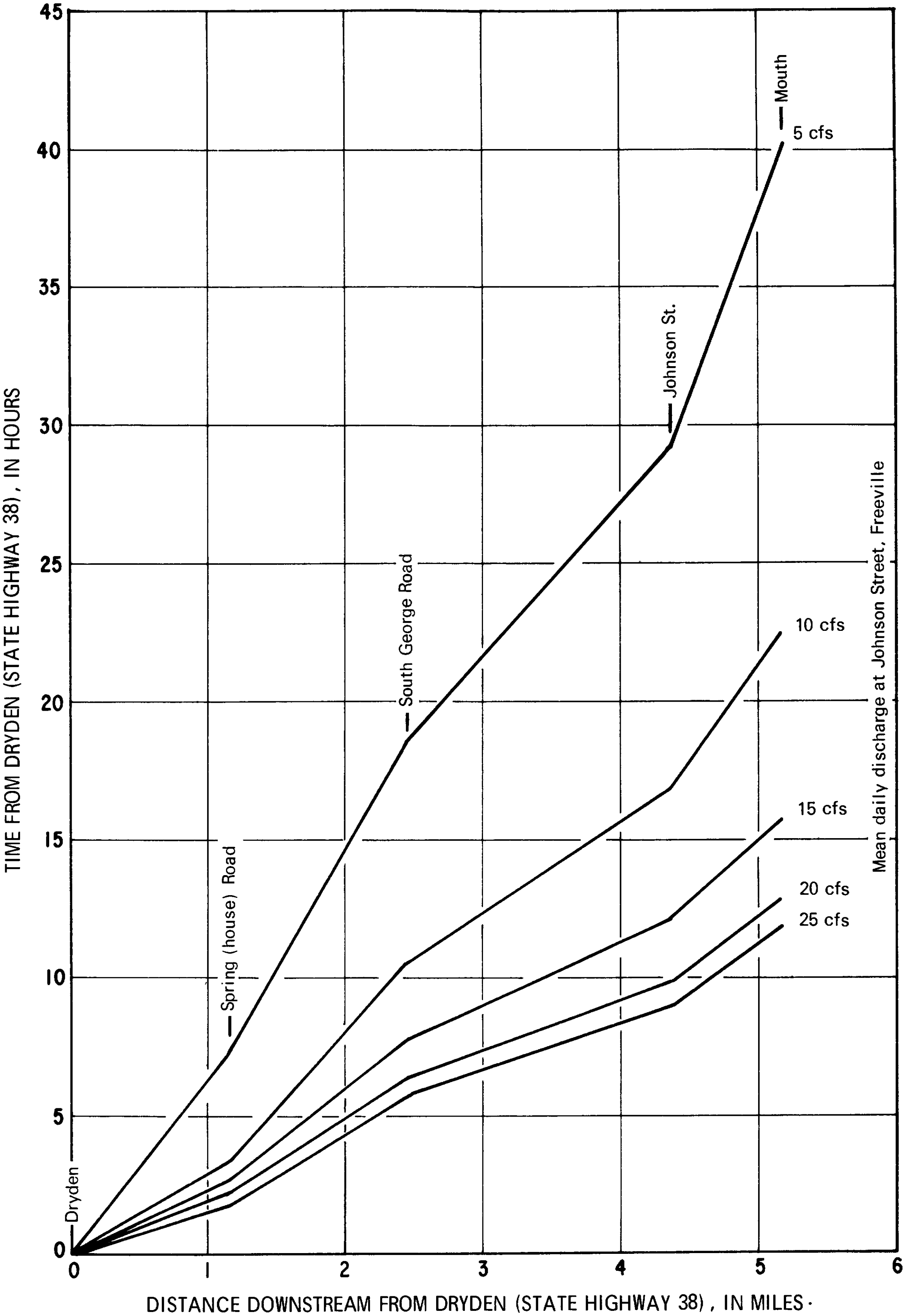

Figure 10.--Time of Travel, Virgil Creek, Dryden (State Highway 38) to mouth.